I – Problem Statement Title (04-GS045)

Development of Reliable Methods to Analyze Battered Piles in Layered Soils and Piles in Sloping Ground to Reduce Foundation Cost

II – Research Problem Statement

Question: How can we develop and improve the design and the analysis of battered piles and piles in sloping ground to increase the design reliability and reduce foundation cost?

Highway bridge piers and abutments are usually supported on deep foundations such as piles and drilled shafts. Pile foundations are also used extensively in offshore and coastal structures. A single pile, a single row of piles in sloping ground or battered piles are commonly used to support highway signs, sound walls and retaining walls. There is no specific procedure used for the design of battered piles or piles in sloping grounds. All of the design recommendations are either simplified or based on crude assumptions. As a result, the designers adopt more conservative design procedures with higher cost.

There are no particular effective procedures or guidelines that handle the analysis of battered piles. The available procedure to analyze battered piles is very simplified and represents a purely structural system approach that ignores the presence of soil. Designers should be cautioned not to rely on such simplified techniques for projects of any significance. It should be noted that the traditional p-y curves that are employed in program LPILE were assessed from tests on laterally loaded vertical piles. Such p-y curves should not be utilized either in the analysis of battered piles or piles into sloping ground.

III – Objective

In recent years, the demand for developing effective design tools and procedures for such elements of foundations under lateral loads has largely increased. Many experimental (model-scale) and field (full-scale) lateral load tests on vertical piles into level ground have been performed nationwide and internationally. However, the full- and model-scale load tests on battered piles or piles into sloping ground are still very limited. As a result, the progress in developing design tools or specific procedures that allow the assessment of response for such particular cases is very slow.

Battered piles and piles in sloping ground share the same features of having characterizations that are different from those of the laterally loaded vertical piles in level ground. Therefore, an appropriate design method for the determination of the lateral load resistance of a battered pile or piles in sloping ground is needed. This procedure should be compiled in a flexible computer program that is used as a design tool.

IV – Background

The California Department of Transportation (CALTRANS) has been one of the leading organizations which sponsored and conducted a large number of research projects, and field and experimental tests on the lateral resistance of piles, drilled shafts, pile caps, and bridge abutments. The basic goal of such research and testing project is to establish reliable design procedures with high certainty and a flexible design tool for such structural elements, which are susceptible to damage under earthquake loading. At present, several research groups have conducted programs of study in order to provide a better understanding of laterally loaded pile and drilled shaft behavior [U. C. Davis, U. C. Los Angeles, University of Texas (Austin), University of California (San Diego), Auburn University (Alabama), etc.]. However, very few of these research efforts have approached or discussed the design of the battered piles or pile into sloping ground.

V – Statement of Urgency and Benefits

A. Support of the Department's Mission/Goals

(Improving Mobility: Safety and Reliability) The successful solution of this problem would improve design procedures. In addition, the study suggested will be verified by using the results of the proposed field tests and other tests conducted by Caltrans. It should be made clear that the data collected from such costly full-scale tests must be compiled into a useful and flexible design tool that can be readily used by the designer. This will allow Caltrans to collect the benefit of conducting such field tests. It will provide cost savings and greater certainty relative to such type of analysis.

B. Return on Investment

The design of battered piles and piles in sloping ground requires clear, verified procedures of analysis. Caltrans typically spends $15M to $20M each year on deep foundations. Clearly defined effective design method with flexible design tool (computer program) allows significant cost savings. Having such a clear design method will reduce the level of uncertainty and the large safety factors used by designers, resulting in the potential savings of millions of dollars.

VI – Related Research

- Reese, L. C., "Behavior of Piles and Pile Groups Under Lateral Load," Report to the U.S. Department of Transportation, Federal Highway Administration, Office of Research, Development, and Technology, Washington, D.C., September, 1983.
- Reese, L. C., *"Behavior of Piles and Pile Groups Under Lateral Load,"* Report to the

U.S. Department of Transportation, Federal Highway Administration, Office of Research, Development, and Technology, Washington, D.C., Report No. FHWA/RD-85/106, March, 1986.

VII – Deployment Potential

As a result of this research and field testing, new design/procedure to predict the response of battered piles and piles in sloping ground or piles supporting bridge abutment. It will provide cost saving and greater certainty relative to such type of analysis.